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DISCHARGE COEFFICIENT OF SWIRL INJECTORS

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DISCHARGE COEFFICIENT OF SWIRL INJECTORS

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ABSTRACT

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Theoretical and experimental investigation of the observed discrepancy between the analytical and actual values of the discharge coefficient of swirl injectors. The results indicate that for fluids with similar physicochemical properties, an increase in the injector outlet diameter leads to a decrease in the discharge coefficient. The dependence of the discharge coefficient on the viscosity and pressure of the atomized fluid differs substantially depending on whether the injectors have large or small outlet diameters.

At present, the postulates of G. N. Abramovich's theory (ref. 1) which is applicable to the ideal fluid, are widely used for the analysis of the mechanism of fluid discharge from swirl injectors. /72 *

As the results of numerous investigations of small capacity nozzles show, the actual coefficients of discharge are substantially higher than the theoretical. For example, in the aviation nozzles, the coefficients of discharge of nozzles with the geometric characteristic $A \geq 2.5$ exceed the theoretical

* Numbers given in the margin indicate the pagination in the original foreign text.

by a factor of 2-3 (ref. 2). It is also established that the difference between the experimental and the theoretical values of the discharge coefficients is greater when the viscosity of the atomized fluid is higher.

This difference, as explained by different authors, is assigned to the influence of the viscosity, which in their opinion, under the motion of the real fluid in the whirl chamber, decreases the whirl effect, and as a result increases the active cross-section of the nozzle (ref. 3).

From this point of view, the theoretical values of the coefficients of discharge should be considered as the lower bound of the actual coefficient reduction. Meanwhile, the data obtained at the All-Union Heat-Engineering Institute (A-UHEI) indicates that the coefficients of discharge of the high capacity nozzles tested are substantially below the theoretical values (fig. 1).

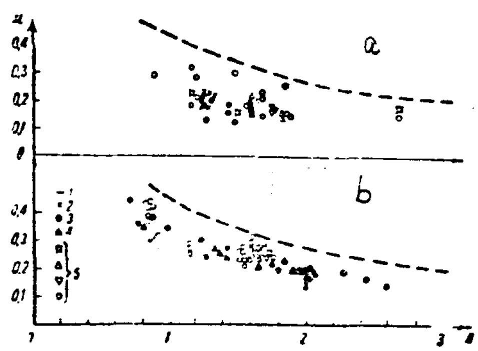

Figure 1. Coefficients of discharge of high capacity nozzles (type 2) as functions of the geometric characteristics, according to the A-UHEI test results. a, for petroleum products; b, for water; 1, theoretical curve according to ref. 1; 2, according to the data of ref. 7; 3, according to the data of A. I. Dvoretskiy and S. T. Karyakin; 4, according to the data of A. I. Dvoretskiy and I. K. Andreev; 5, according to authors' data.

According to L. D. Berman (ref. 4), the discrepancy between the theoretical and the experimental values of the coefficients of discharge is due to the effect of constructional and manufacturing nozzle defects.

The reduction of the coefficient of discharge in the high capacity mass produced nozzles, in our opinion, is impossible to explain by the reasons of the manufacturing defects, since the reduced coefficients were obtained even in nozzles with the accurately polished active surfaces. These reasons do not easily explain the presence of the coefficients of discharge which are higher than the theoretical.

In order to establish the influence of the nozzle constructional variables on the degree of divergence between the theoretical and the experimental values of the discharge coefficients, we have analyzed the reports of research on the different variants of the manufactured nozzles. A particular emphasis is placed on the data obtained by one and the same experimenter, testing a large number of nozzles of different construction. For example, the systematic investigations were carried out by Doble (ref. 5) and Radcliffe (ref. 6). Each one of them determined the discharge characteristics of more than 240 nozzles of different construction.

Since in the tests of one of the investigators the degree of the nozzle surface finish was the same, it seems that it may be assumed that the magnitude of the deviation between the experimental and the theoretical values of the discharge coefficients, would characterize the degree of the nozzle construction /73 perfection. But, as the analysis of the reports showed, it is impossible to judge the degree of nozzle construction perfection by the divergence between the theoretical and the experimental values of the discharge coefficient, since this quantity is determined more by the absolute dimensions of the nozzle exit area than by the relative geometrical dimensions of the nozzle.

Radcliffe's and Doble's data, presented in the form of graphical relationships between μ and A (figs. 2 and 3), are displayed as curves, each of which corresponds to the nozzles with the same cross-section, but different combination of the whirl chamber dimensions and the number of inlet channels.

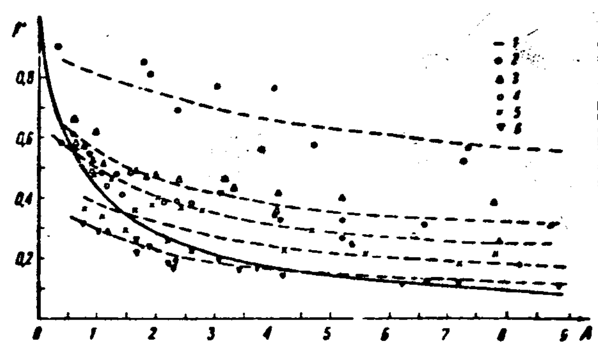

Figure 2. Coefficient of discharge as a function of the geometric characteristic and the nozzle dimension, according to Radcliffe. 1, theoretical curve according to ref. 1; 2, d_c = 0.5 mm; 3, d_c = 0.76 mm; 4, d_c = 1.01 mm; 5, d_c = 1.93 mm; 6, d_c = 3.05 mm

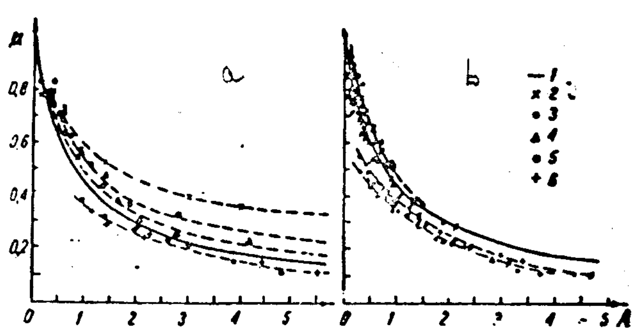

Figure 3. Coefficient of discharge as a function of the geometric characteristic, according to Doble, for the nozzles with the circular cross-section (a); rectangular cross-section (b). 1, theoretical curve according to ref. 1; 2, d_c = 1.59 mm; 3, d_c = 3.18 mm; 4, d_c = 4.76 mm; 5, d_c = 11.2 mm; 6, d_c = 12.7 mm.

A relatively small spread of the experimental points in relation to the aver- /74 age curve indicates that the nozzle constructional parameters (the whirl chamber radius, the dimensions and the number of inlet channels) have only a small effect on the values of the coefficients of discharge.

The ratios of the whirl chamber radius to the nozzle radius, and the cross-sectional area of the inlet channels to the cross-section area of the nozzle, varied widely in all of the performed tests. In these tests there were two to four inlet channels. The coefficients of discharge, for all practical purposes, did not depend on the pressure of the flowing fluid.

Moreover, from the collection of curves shown in figures 2 and 3, and also from the experimental results of Radcliffe and Doble it may be seen that the nozzles with the small dimensions are characterized by the higher discharge coefficients in comparison with the theoretical values. As the nozzle dimensions are increased, the coefficients of discharge are systematically reduced, and as the relatively large nozzle dimensions are approached, they become smaller than the theoretical values. An analogous interrelationship also exists between the nozzle coefficients of discharge and the size of the nozzle exit area, as the analysis of the results of other investigators indicate.

Therefore, the values of the discharge coefficients depend not only on the dimensionless geometric characteristic of the nozzle, but also on the absolute nozzle dimension, i.e., its diameter. The absolute dimension of the nozzle diameter affects the character of the influence of the viscosity and the pressure of the atomized fluid on the nozzle discharge coefficient. /75

The results of studying the influence of the viscosity on the nozzle coefficient of discharge, for the nozzle with the diameter $d_c = 6.8$ mm, and the geometric characteristic A = 1.16, as well as the test data obtained for the nozzles with nearly equal geometric dimensions (d_c = 8.0 mm; A = 1.26), are brought forth in ref. 7, and shown in figure 4. It can be seen from figure 4 that, as the viscosity of the fluid is increased, the discharge coefficient of the high capacity nozzles is systematically reduced (a similar reduction is observed when the pressure is decreased).

Thus, the influence of the viscosity on the coefficient of discharge is not limited solely by the reduction of the swirl action of the emanating fluid; it is considerably more complex. /76

The generalized dependence of the ratio of the actual discharge coefficient μ to the theoretical μ_0, as a function of the Reynold's criterion is shown in figure 5, for the various nozzles of different constructions. The Reynold's criterion (Re) pertains to the nozzle diameter and the theoretical velocity of the ejected fluid. The range of variation of the nozzle parameters of different constructions are presented in the table.

In the performed tests the viscosity varied between 0.65-0.63 centistoke, and the pressure from 1 to 40 kg/cm^2.

The data from the table and figure 5 indicate that as the Reynold's criterion is increased, the value of μ/μ_0 increases and approaches 1.

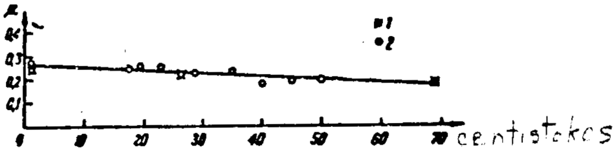

Figure 4. Coefficient of discharge of high capacity nozzles as a function of the fluid viscosity, according to the A-UHEI test results. 1, data from ref. 7; 2, authors' data.

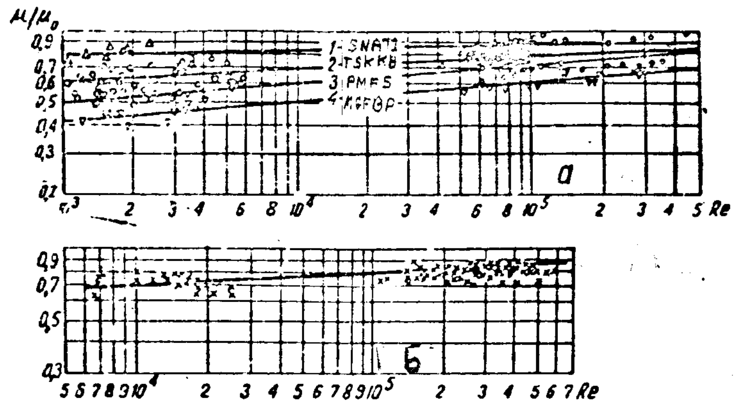

Figure 5. Dimensionless dependence $\mu/\mu_0 = f(Re)$ for the high capacity nozzles: according to the authors' data; a, A. I. Dvoretskiy (1, 2, 3, 4 - according to type number); and b, S. T. Karyakin (type 2).

TABLE

Nos. correspond to Figure 5	Nozzle type			Measurement range for nozzle parameters				
	Channel Shape	Relative dia. whirl chamber D_{wc}/d_c	Relative length [illegible]	d_c	D_{wc}	d_{iu}	n	A
				**				
1	Circular	2,4- 2,9	0,55 0,66	4,5- 5,5	13,0	6,0	4	2,2 - 2,7
2	Rectangular	1,4—4,5	0,28—0,66	4,5—10,1	9,1 - 21,1	5,3— 7,8	2	0,79—2,94
3	"	2,5—4,2	0,38—0,51	5,0— 8,6	21,0—21,3	10,8 —11,2	6	1,07—1,18
4	"	1,0—1,3	0,24 0,49	7,9- 10,1	10,0 —13,5	6,3— 7,5	3	0,54—1,51

Thus, the functional dependence $\mu/\mu_0 = f(Re)$, for the large capacity nozzles, differs in quality from the equivalent dependence of the small capacity nozzles, in which the coefficient of discharge systematically decreases as the criterion (Re) is increased.

Note: d_{iu} is the equivalent diameter of the inlet channels; n is the number of channels.

The recorded effect of the nozzle dimension influence on the coefficient of discharge indicates that the nature of the motion of the fluid in the nozzle can hardly be described by the general relationships of criteria, as they are usually utilized in the solution of hydrodynamic problems. Evidently the relationship of the nozzle intake energy to the energy of the fluid in swirling motion, which determines the nozzle coefficient of discharge, depends on the ratio of the nozzle outlet dimension to the thickness of the boundary layer.

The following becomes obvious: as a rule, the values of the discharge coefficients of the nozzles with similar geometric characteristics, differ considerably from the theoretical values; the increase of the nozzle exit area, when fluids possessing the same physical and chemical properties are ejected, leads to the reduction of the discharge coefficient; the functional dependence of the discharge coefficient on the viscosity and the pressure of the ejected fluid is highly different in character for the nozzles with small and large dimensions of the exit areas.

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